THERMODYNAMICS & FIRST LAW

SOLUTIONS TO THE PROBLEM SET

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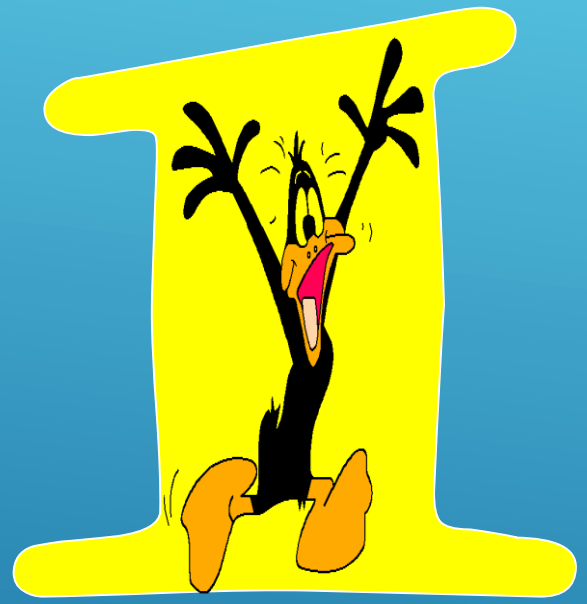

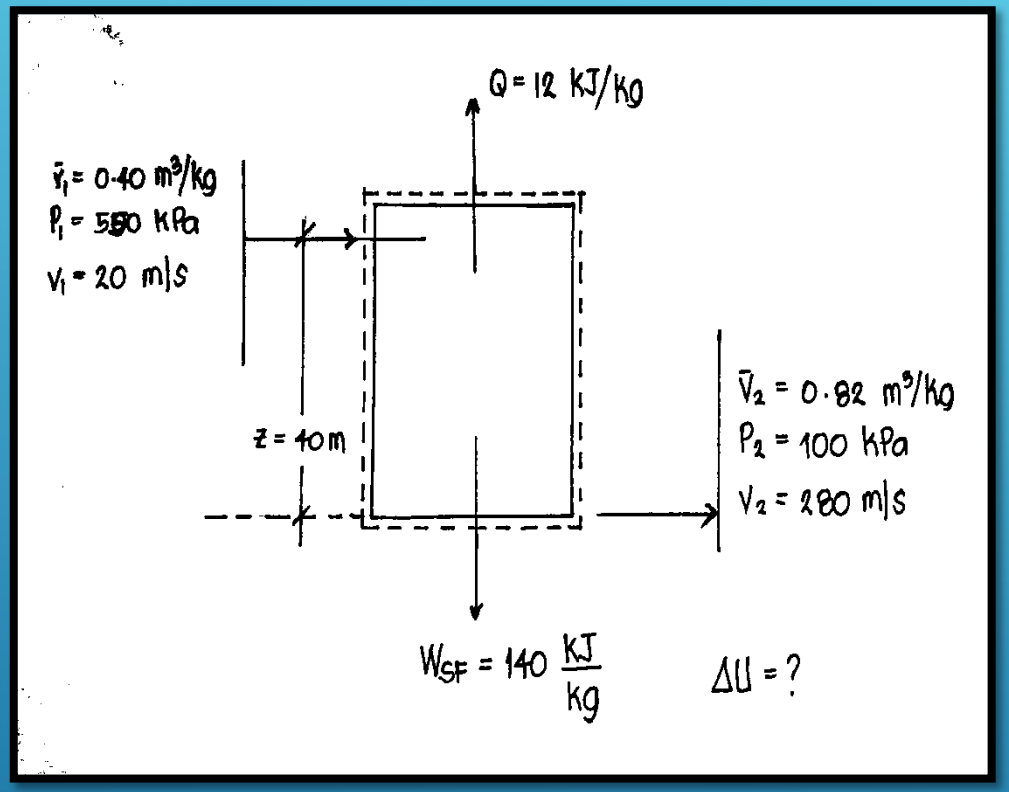
Q = 12 KJ/kg
$\bar{v}_1$ = 0.40 m³/kg
P_1 = 580 kPa
V_1 = 20 m/s
z = 40 m
$\bar{V}_2$ = 0.82 m³/kg
P_2 = 100 kPa
V_2 = 280 m/s
W_{SF} = 140 KJ/kg
ΔU = ?

Applying the First Law of Thermodynamics;

$$[E_{IN} = E_{OUT}]$$

$$PE_1 + KE_1 + U_1 + W_{f_1} = Q + W_{SF} + PE_2 + KE_2 + U_2 + W_{f_2}$$

$$-\Delta U = Q + W_{SF} + \Delta PE + \Delta KE + \Delta W_f;$$

For ΔPE;

$$\Delta PE = m\left(\frac{g_o}{g_c}\right)z$$

$$\frac{\Delta PE}{m} = \frac{9.81\ \frac{m}{s^2}}{1000\ \frac{kg-m}{kN-s^2}}(40\ m) = 0.3924\ \frac{kJ}{kg}$$

For ΔKE;

$$\Delta KE = \frac{1}{2}\frac{m}{g_c}(v_2{}^2 - v_1{}^2)$$

$$\frac{\Delta KE}{m} = \frac{1}{2}\frac{(280^2 - 20^2)\frac{m^2}{s^2}}{\left(1000\,\frac{kg-m}{kN-s^2}\right)} = 39\ \frac{kJ}{kg}$$

For ΔW_f;

$$\Delta W_f = m(P_2\bar{v}_2 - P_1\bar{v}_1)$$

$$\frac{\Delta W_f}{m} = \left[\left(100\,\frac{kN}{m^2}\right)\left(0.82\,\frac{m^3}{kg}\right) -\right.$$

Substituting values;

$$-\Delta U = 12\ \frac{kJ}{kg} + 140\ \frac{kJ}{kg} + 0.3924\ \frac{kJ}{kg} + 39\ \frac{kJ}{kg} - 138\ \frac{kJ}{kg}$$

$$\mathbf{\Delta U = -53.39\ \frac{kJ}{kg}}$$

The internal energy decreases

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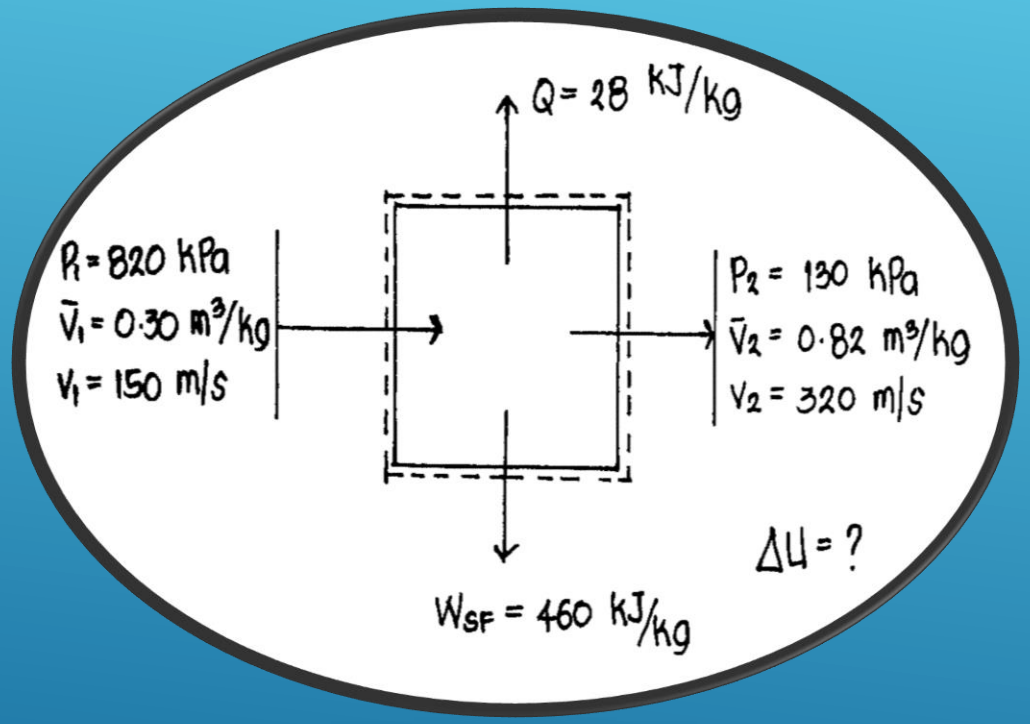

Q = 28 kJ/kg
P1 = 820 kPa
V̄1 = 0.30 m³/kg
V1 = 150 m/s
P2 = 130 kPa
V̄2 = 0.82 m³/kg
V2 = 320 m/s
ΔU = ?
WSF = 460 kJ/kg

Applying the First Law of Thermodynamics;

$$[E_{IN} = E_{OUT}]$$

$$PE_1 + KE_1 + U_1 + W_{f_1} = Q + W_{SF} + PE_2 + KE_2 + U_2 + W_{f_2}$$

$$-\Delta U = Q + W_{SF} + \Delta PE + \Delta KE + \Delta W_f; \qquad \Delta PE \approx 0$$

For ΔKE;

$$\Delta KE = \frac{1}{2}\frac{m}{g_c}(v_2{}^2 - v_1{}^2)$$

$$\frac{\Delta KE}{m} = \frac{1}{2}\frac{(320^2 - 150^2)\frac{m^2}{s^2}}{\left(1000\,\frac{kg-m}{kN-s^2}\right)} = 39.95\ \frac{kJ}{kg}$$

For ΔW_f;

$$\Delta W_f = m(P_2\bar{v}_2 - P_1\bar{v}_1)$$

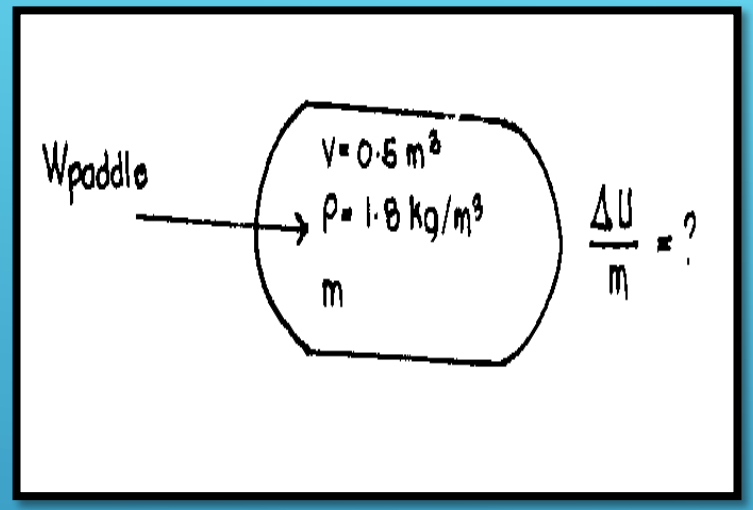
$$\frac{\Delta W_f}{m} = (P_2\bar{v}_2 - P_1\bar{v}_1)$$

$$\frac{\Delta W_f}{m} = \left[\left(130\,\frac{kN}{m^2}\right)\left(0.82\,\frac{m^3}{kg}\right) -\right.$$

Substituting values;

$$-\Delta U = 28\ \frac{kJ}{kg} + 460\ \frac{kJ}{kg} + 39.95\ \frac{kJ}{kg} - 139.4\ \frac{kJ}{kg}$$

$$\boldsymbol{\Delta U = -388.55\ \frac{kJ}{kg}}$$



$$W_{paddle} = \Delta U$$

$$\frac{W_{paddle}}{m} = \frac{\Delta U}{m} = \frac{5.5\,\frac{J}{s}(30\text{ min})\left(\frac{60\text{ s}}{1\text{ min}}\right)}{1.8\,\frac{kg}{m^3}(0.5\text{ m}^3)} = 11{,}000\ \frac{J}{kg}$$

$$\mathbf{\frac{\Delta U}{m} = 11\ \frac{kJ}{kg}}$$

Applying the First Law of Thermodynamics;

$$[E_{IN} = E_{OUT}]$$

$$\begin{bmatrix}\text{Initial energy}\\ \text{stored within}\\ \text{the system}\end{bmatrix} + \begin{bmatrix}\text{Initial energy}\\ \text{entering the}\\ \text{system}\end{bmatrix} = \begin{bmatrix}\text{Final energy}\\ \text{stored within}\\ \text{the system}\end{bmatrix} + \begin{bmatrix}\text{Final energy}\\ \text{entering the}\\ \text{system}\end{bmatrix}$$

$$PE_1 + KE_1 + U_1 + Q + W_{paddle} = W_{piston} + PE_2 + KE_2 + U_2$$

$$Q = W_{piston} - W_{paddle} + \Delta PE + \Delta KE + \Delta U; \quad \Delta PE \approx 0 \text{ and } \Delta KE \approx 0$$

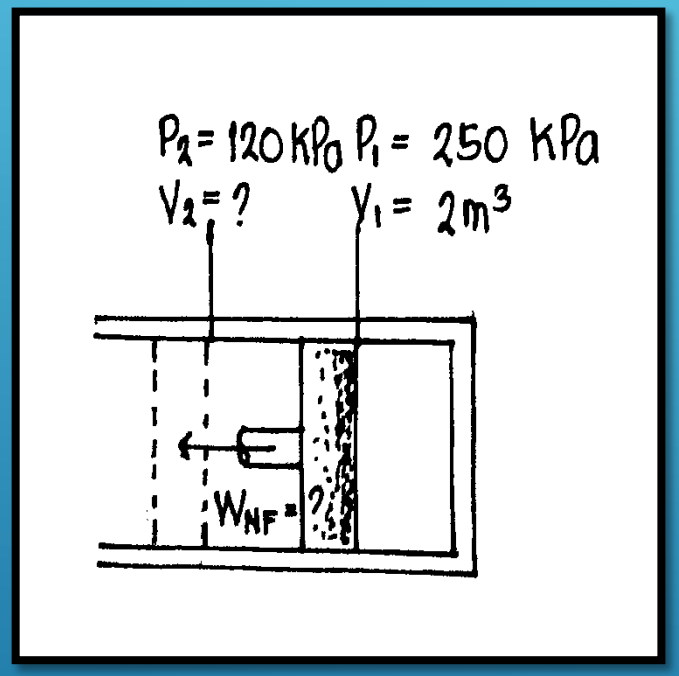
$$Q = W_{piston} - W_{paddle} + \Delta U$$

Substituting values;

$$\frac{75}{8}\frac{\text{kJ}}{\text{kg}} = \text{W}_{\text{piston}} - \frac{20}{8}\frac{\text{kJ}}{\text{kg}} + (2660.5 - 2710.0)\frac{\text{kJ}}{\text{kg}}$$

$$\text{W}_{\text{piston}} = 61.375\ \frac{\text{kJ}}{\text{kg}}(8\ kg)$$

$$\mathbf{W_{piston} = 491\ kJ}$$



$$W_{NF} = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$PV = C$$

$$P_1 V_1 = P_2 V_2$$

$$(250\ \text{kPa})(2\ \text{m}^3) = (120\ \text{kPa})(V_2)$$

$$V_2 = \frac{25}{6}\ \text{m}^3$$

$$W_{NF} = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$W_{NF} = \left(250\ \frac{kN}{m^2}\right)(2\ m^3)\ln\left(\frac{\frac{25}{6}\ m^3}{2\ m^3}\right)$$

$$\mathbf{W_{NF} = 366.98\ kJ}$$

Applying the First Law of Thermodynamics;

$$[E_{IN} = E_{OUT}]$$

$$W_{paddle} = W_{piston} + \Delta PE$$
$$W_{piston} = W_{paddle} - \Delta PE$$

For W_{paddle};

$$W_{paddle} = P\Delta V$$
$$W_{paddle} = 100\ \frac{kN}{m^2}(0.0025\ m^3) = 0.25\ kJ$$

For ΔPE;

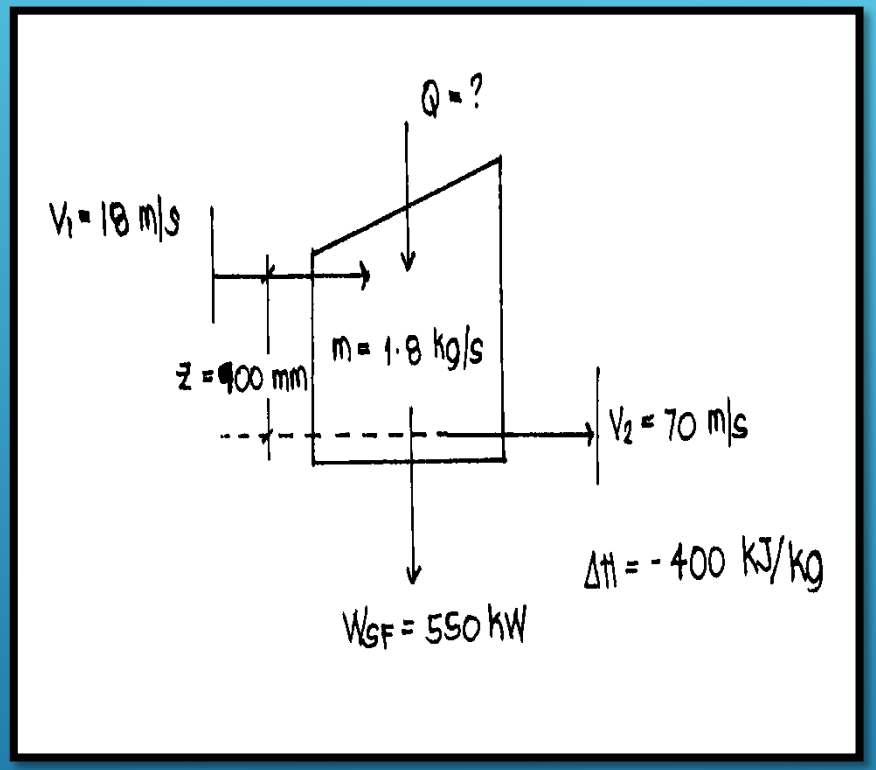
$$\Delta PE = m\left(\frac{g_o}{g_c}\right)(z)$$

$$\Delta PE = 120\ kg\left(\frac{9.81\ \frac{m}{s^2}}{1000\ \frac{kg-m}{kN-s^2}}\right)(4\ m) = 4.7088\ kJ$$

Substituting values;

$$W_{piston} = 0.25\ \text{kJ} - 4.7088\ \text{kJ}$$

$$\mathbf{W_{piston} = -4.46\ kJ}$$


Q = ?
V1 = 18 m/s
z = 400 mm
m = 1.8 kg/s
V2 = 70 m/s
Δh = - 400 kJ/kg
WSF = 550 kW

Applying the First Law of Thermodynamics;

$$[E_{IN} = E_{OUT}]$$

$$PE_1 + KE_1 + U_1 + W_{f_1} + Q = W_{SF} + PE_2 + KE_2 + U_2 + W_{f_2}$$

$$-Q = W_{SF} + \Delta PE + \Delta KE + \Delta U + \Delta W_f; \qquad \Delta H = \Delta U + \Delta W_f$$

$$-Q = W_{SF} + \Delta PE + \Delta KE + \Delta H$$

For ΔPE;

$$\Delta PE = m\left(\frac{g_o}{g_c}\right)z$$

$$\Delta PE = 1.8\ \frac{kg}{s}\left(\frac{9.81\ \frac{m}{s^2}}{1000\ \frac{kg-m}{kN-s^2}}\right)(0.9\ m) = 0.01589\ kW$$

For ΔKE;

$$\Delta KE = \frac{1}{2}\frac{m}{g_c}\left(v_2{}^2 - v_1{}^2\right)$$

$$\Delta KE = \frac{1}{2}\left(\frac{1.8\ \frac{kg}{s}}{1000\ \frac{kg - m}{kN - s^2}}\right)\left(70^2 - 18^2\right)\frac{m^2}{s^2} = 4.1184\ kW$$

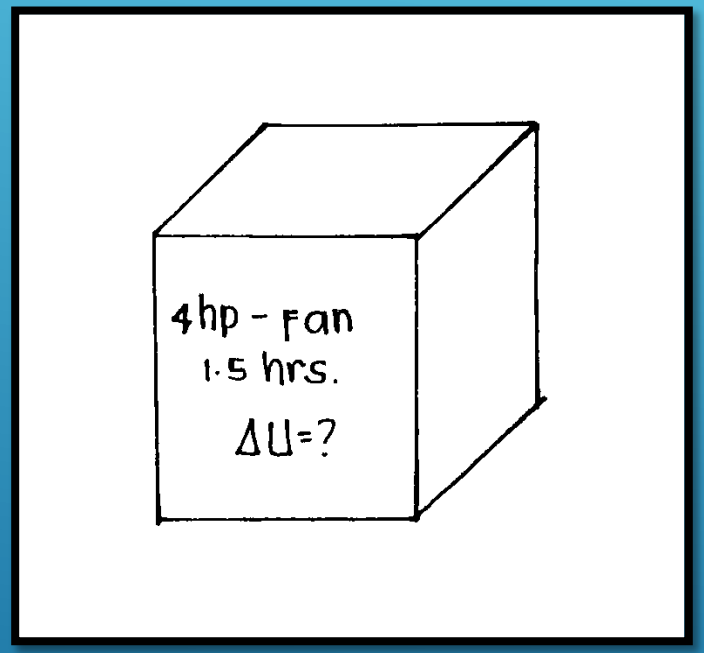
For ΔH;

$$\Delta H = -400\ \frac{kJ}{kg}\left(1.8\ \frac{kg}{s}\right) = -720\ kW$$

Substituting values;

$$\mathrm{Q} = 550\ \mathrm{kW} + 0.01589\ \ \mathrm{kW} + 4.1184\ \mathrm{kW} - 720\ \mathrm{kW}$$

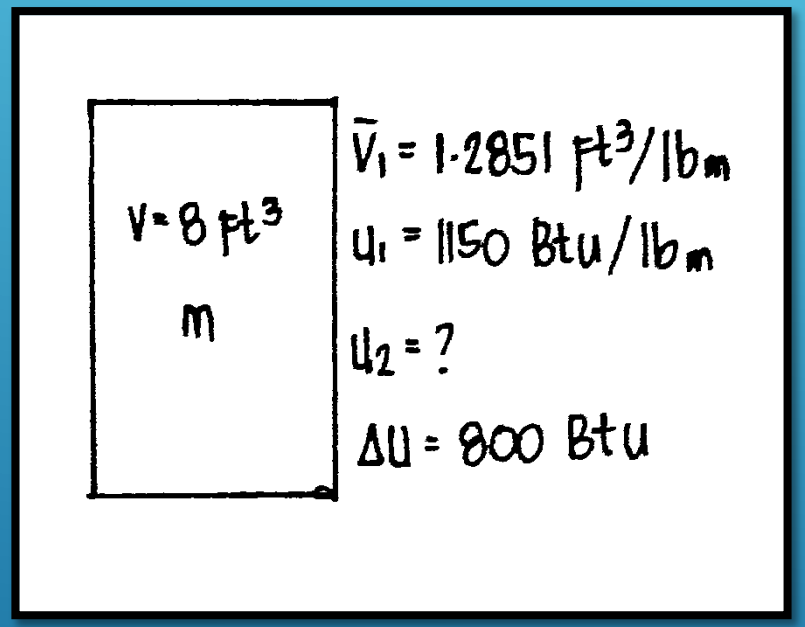
$$\mathbf{Q = -165.90\ kW}$$



$$\Delta U = 4\ \text{hp}\left(\frac{746\ \frac{\text{J}}{\text{s}}}{1\ \text{hp}}\right)$$

$$\Delta U = 2984\ \frac{\text{J}}{\text{s}}(1.5\ \text{hr})\left(\frac{3600\ \text{s}}{1\ \text{hr}}\right)$$

$$\boldsymbol{\Delta U = 1.61 \times 10^{7}\ \text{J}}$$



$$\Delta U = m(u_2 - u_1)$$

$$m = \frac{V}{\bar{v}}$$

$$800\ \text{Btu} = \frac{8\ \text{ft}^3}{1.2851\ \frac{\text{ft}^3}{\text{lb}_\text{m}}}\left(u_2 - 1150\ \frac{\text{Btu}}{\text{lb}_\text{m}}\right)$$

$$\mathbf{u_2 = 1278.51\ \frac{Btu}{lb_m}}$$

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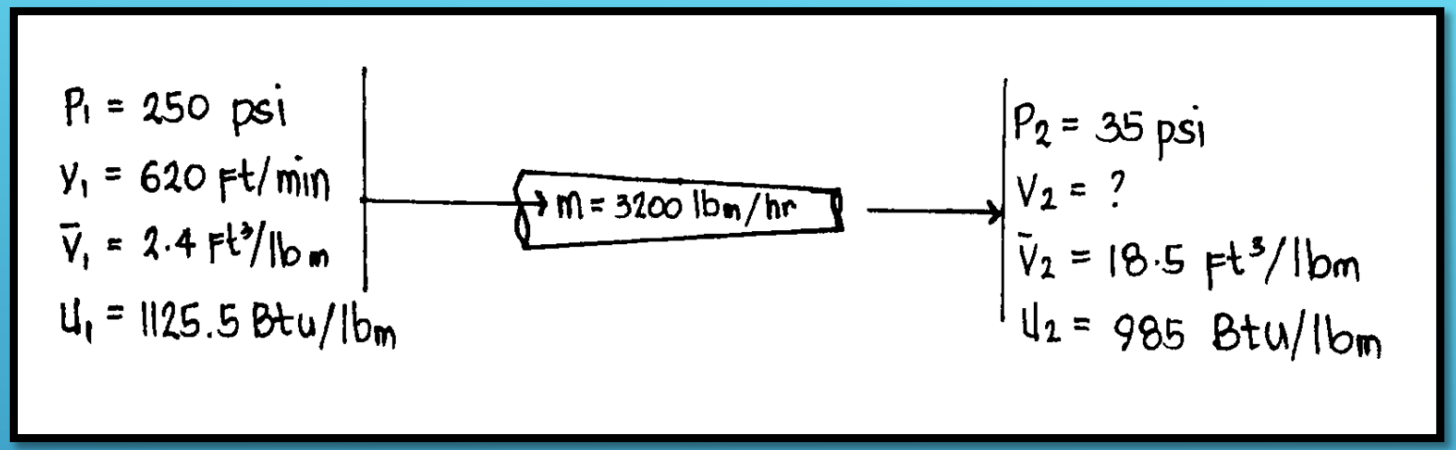

Applying the First Law of Thermodynamics;

$$[E_{IN} = E_{OUT}]$$

$$PE_1 + KE_1 + U_1 + W_{f_1} = Q + W_{SF} + PE_2 + KE_2 + U_2 + W_{f_2}$$

$$-\Delta KE = Q + \Delta PE + \Delta U + \Delta W_f; \qquad \Delta PE \approx 0 \text{ and } Q \approx 0$$

$$-\Delta KE = \Delta U + \Delta W_f$$

For ΔU;

$$\Delta U = m(u_2 - u_1)$$

$$\Delta U = 3200\ \frac{lb_m}{hr}(985 - 1125.5)\frac{Btu}{lb_m} = -449,600\ \frac{Btu}{hr}\left(\frac{778.169\ \ ft - lb_f}{1\ Btu}\right)\left(\frac{1\ hr}{3600\ s}\right)$$

$$\Delta U = -97,184.66\ \frac{ft - lb_f}{s}$$

For ΔW_f;

$$\Delta W_f = m(P_2\bar{v}_2 - P_1\bar{v}_1)$$

$$\Delta W_f = 3200\ \frac{lb_m}{hr}\left[\left(35\ \frac{lb}{in^2}\right)\left(18.5\ \frac{ft^3}{lb_m}\right) - \left(250\ \frac{lb}{in^2}\right)\left(2.4\ \frac{ft^3}{lb_m}\right)\right](144\ in^2)$$

$$\Delta W_f = 21,888,000\ \frac{ft - lb_f}{hr}\left(\frac{1\ hr}{3600\ s}\right) = 6080\ \frac{ft - lb_f}{s}$$

Substituting values;

$$-\Delta KE = -97,184.66\ \frac{ft-lb_f}{s} + 6080\ \frac{ft-lb_f}{s}$$

$$-\left[\frac{1}{2}\frac{m}{g_c}\left(v_2{}^2 - v_1{}^2\right)\right] = -91,104.66\ \ \frac{ft-lb_f}{s}$$

$$-\left[\frac{1}{2}\left(\frac{3200\frac{lb_m}{hr}\times\frac{1\ hr}{3600\ s}}{32.2\frac{lb_m-ft}{lb_f-s^2}}\right)\left(v_2{}^2 - \left(620\ \frac{ft}{min}\times\frac{1\ min}{60\ s}\right)^2\right)\right] = -91,104.66\ \ \frac{ft-lb_f}{s}$$

$$\mathbf{v_2 = 2569.17\ \frac{ft}{s}}$$

– End –

To God be the Glory!